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**An Estimation of Available Cellulosic Biomass in Ten Counties in
Northeastern Arkansas from 1999-2011**

An Undergraduate Honors College Thesis
in the
Biological and Agricultural Engineering Department
College of Engineering
University of Arkansas
Fayetteville, AR

by
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April 26, 2013

This thesis is approved.

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Abstract

The purpose of this research is to explore the possibility of siting a biorefinery that produces cellulosic ethanol in the Delta region of Arkansas, which is the main agricultural area of the state. Four major crops that the state of Arkansas produces on a yearly basis that could potentially be used for cellulosic ethanol production are: corn, rice, sorghum, and soybeans. This research will result in the generation of maps that will be useful in quantifying feedstock produced in the Delta region of Arkansas, which can be used by a biorefinery. An actual site will not be chosen based strictly off this research. However, the general area for the location of the biorefinery could be inferred from the results of this research.

In order to help determine the best location for the refinery, the ten counties of the Delta region were ranked by how much of each crop they produced from 1999-2011. A Geographic Information System (GIS), that included the Cropland Data Layer, was used as the primary data source for land usage in each county. The amount of land used for each type of crop in each county was then converted into how much of each type of crop was produced. The yearly totals were averaged together and then the counties were ranked by crop production for each crop.

Throughout the Delta region in the state there were pockets of concentrated areas of each crop. Sorghum was concentrated in the southern part of the Delta, rice was concentrated in the center of the Delta region, and corn was concentrated in the northern and southern tips of the Delta region. Soybeans were the exception to the trend, each county produced about the same amount of soybeans.

Introduction

Overview

Biofuels could play a major role in the energy market as renewable energy becomes more and more important in modern society. Turning cellulosic biomass into biofuel is a growing technology and the placement of the biorefinery is vital in keeping costs low. The ideal location of a biorefinery would be where all transportation costs were minimized as much as possible. In order to keep transportation costs low, the site of the biorefinery must be strategically selected. Therefore, the main goal of this research is to establish how much cellulosic biomass the northeastern part of the state of Arkansas can contribute to a biorefinery on a yearly basis.

Literature Review

As the modern world continues to use up nonrenewable resources for energy, the demand for technology that utilizes renewable resources will increase. The major source of energy used today, for transportation, is petroleum. In the year 2009 the United States consumed 94.6 quads of energy, 25.52 quads of this energy was used for transportation from petroleum products (U.S. Department of Energy 2013). For scale one Quad is the equivalent of 172 million barrels of oil. It is a well-known fact that oil is a non-renewable resource and at current use rates the United States cannot continue to use that much oil forever. Eventually an alternative source of energy will be needed. In the year 2050, it is predicted that the world will only be able to produce 40 million barrels of oil (U.S. Department of Energy 2013), which is only about one fourth the oil of what the U.S. currently consumes. Therefore, an alternative source(s) of energy is needed to make up the difference of required energy.

One source of energy that has potential to make an impact on the transportation energy market is biofuels. In the year 2012, 13.3 million gallons of ethanol were produced in the United States (Renewable Fuels Association 2013), which is about 10% of actual oil consumption. With research and development, biofuels could become a major contributor to the liquid fuel market. The current reason why more ethanol is not being made from corn is because corn belongs to another major market, the food industry. High fructose corn syrup is found in many foods and beverages that the U.S. population consumes on a daily basis: soft drinks, breakfast cereal, yogurt, salad dressing, and many other foods (Ryan 2011). Corn grain is also used as feed to cattle that provides beef to the U.S. market as well. Taking corn away from the food industry and allowing it to be used as a fuel source is a very controversial topic. One special interest group that lobbies to Congress about the food versus fuel debate has an ongoing petition. Their argument claims that the Renewable Fuel Standards (RFS) act is one reason food prices have been rising in recent years (American Meat Institute 2011). The issue does not seem to be going away. However, the RFS act is still in effect and requires a certain amount of fuel used in cars to be from renewable sources. This has led to changes at the gas pump including: E85 Flex Fuel (85% ethanol) and regular unleaded gasoline which must contain 10% ethanol (Office of Transportation and Air Quality 2013). If the regulation continues by the year 2022 the U.S. will use 36 billion gallons of biofuels (U.S. Department of Energy 2013). Congress has stated that it will review the RFS because Congress now has “a wealth of actual implementation experience with [corn ethanol]” (Shepardson 2013).

Researchers have found a way to produce ethanol from corn without using the grain and thus compromising the food market's needs. The crop residue, the unused part of the corn crop, can be converted in ethanol; the specific name for this type of fuel is "Cellulosic Ethanol". As part of the 36 billion gallon biofuel RFS mandate, 21 billion gallons must come from advanced cellulosic ethanol. (Shepardson 2013)

Background – Cellulosic Biofuel Production

The energy used for food and fuel in the corn grain is sugar. The residue is the part of the plant that is not harvested, is also sugar. The big difference between the corn grain and the residue is the type of bond that connects the individual monomers together. The corn grain contains starch that is linked by an alpha (α) bond; humans can digest polysaccharides with alpha bonds because these bonds are not as stable as beta bonds (Hardinger 2013). Corn grain contains two types of starch: amylose and amylopectin. Amylose is straight chained and has α 1, 4 linkages. Amylopectin is branched and has α 1, 4 linkages and α 1, 6 linkage. See figure 1 for graphical illustrations of amylose and amylopectin. The starches are hydrolyzed into individual monomers by specific enzymes and are further processed into ethanol (Brown 2003).

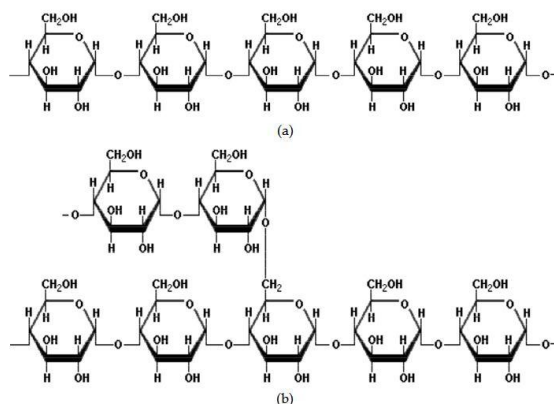


Figure 1. The top chain is the straight chained amylose and the bottom chain is the branched amylopectin.

Corn residue is also composed of sugars but these sugars are not as easy to access because, they are contained inside the cell wall and are linked together by a different type of bond. The cell wall, also referred to as lignocellulose, is made up of cellulose, hemicellulose, and lignin. The cellulose and hemicellulose contain sugars like starch but are joined by a beta (β) linkage instead of an alpha (α) linkage. The beta linkage is more stable than the alpha linkage (Hardinger 2013). See figure 2 for illustration of an alpha bond and a beta bond. The lignin cannot be used for ethanol production. Lignin is not susceptible to biological transformation into fuel. (Brown 2003)

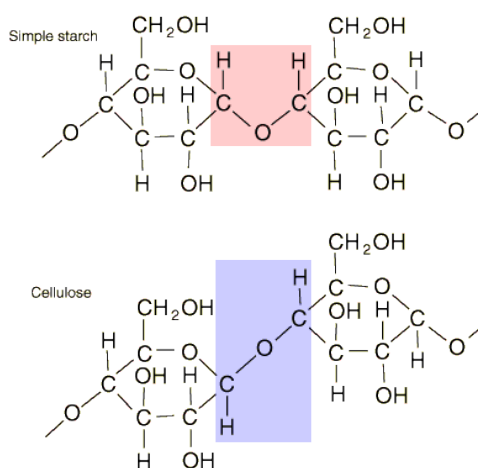


Figure 2. Above are two disaccharide. The top disaccharide contains the alpha bond, note the downward orientation of the bond. The bottom disaccharide contains a beta bond, note it does not have a downward orientation.

The basic process of taking lignocellulosic feedstock to ethanol consists of: pretreatment, hydrolysis, fermentation, and distillation. The first pretreatment step consists of grinding the crop residue. The residue needs to be ground to smaller pieces to increase the surface area of the residue. More surface area makes the polysaccharides better prepared for the next step in the process, hydrolysis (Brown 2003). Hydrolysis is the release of cellulose and hemicellulose from the lignocellulosic matrix. There are several methods to hydrolyze the sugars. However, the most

common method used is to treat the biomass with acid at a high temperature to release the cellulose and hemicellulose (NREL 2011). Regardless of the specific pretreatment method that is used, they all have the same goal which is to improve the digestibility of lignocelluloses (Brown 2003). The specifics of pretreatment are unique for each type of crop residue, so the sugar content is maximized (Brown 2003). After the pre-treatment, the cellulose and hemicellulose are ready to be hydrolyzed by enzymes.

Hydrolysis is the process of cleaving the bonds that connect polysaccharide chains. There are three different hydrolysis methods, concentrated-acid hydrolysis, dilute-acid hydrolysis, and enzymatic hydrolysis. The two acid processes require very little preparation work when compared to the enzymatic process. For the enzymatic process the lignin, cellulose, and hemicellulose must be separated extensively (Brown 2003). Also, if the enzymatic process is used the pH must be at the correct level in order for the enzyme to function correctly. Some base material must be added to the biomass mixture if acid pretreatment is used (NREL 2011). The reason for the extensive separation of the different components is because of the specificity of the enzymes used. The enzyme has a specific target and it will not function if it is not able to find its target molecule. (Worthington Biochemical Corporation 2013) Once the cellulose and hemicellulose have been hydrolyzed the hydrolyzate is ready for fermentation.

Fermentation is the step in the process of that converts hydrolyzate to ethanol. Before the actual fermentation the hydrolyzate needs to be cleansed. If the hydrolyzate contains compounds that will prevent fermentation organisms from growing the minimal ethanol will be produced (Brown 2003). The methods for cleansing the hydrolyzate vary, but they include: addition of activated carbon, extraction with organic solvents, ion

exchange, ion exclusion, molecular sieves, over-liming, and steam stripping. (Brown 2003). Multiple sugar types are present in the hydrolyzate therefore multiple fermentation organisms are needed to maximize the fermentation product.

Distillation is the final step in the process and is the method of used for the separation of ethanol from other side products produced during fermentation. Corn residue is a viable option to make ethanol and it is supported by the federal government. However, several extra steps are required in order to reach the sugar and make the ethanol.

Arkansas and Biofuel

Cellulosic ethanol can be made from any crop residue, not just corn. Four crops that are potential candidates to provide cellulosic material for biorefinery in Arkansas are: corn, rice, soybeans, and sorghum. (National Agricultural Statistics Service 2012) In Arkansas, the leading crop is not corn, but rice. Arkansas produces 47% of the rice supply for the United States (NetState 2012). Soybeans are the second most valuable commodity in the state and rice is the third most valuable (Parker 2013). On a biochemical scale, the cell wall is virtually the same composition in all plants: cellulose, hemicellulose, and lignin. The logistics and specifics of the process to produce ethanol may change some but the core idea would remain the same. The core idea is to take crop residue that is not being used by the farmer, extract the sugars, and ferment them into ethanol. The flexibility of this energy source allows the process to be adapted to local areas, depending on the local agricultural crops available. Little data is available

on making cellulosic ethanol from soybean and rice residue and further research is required to make this a reality.

Opening a biorefinery would complement the Arkansas economy well because one the state's main industries is agriculture (NetState 2012). A biorefinery would use what is simply 'waste' to the farmers of the state and turn it into a useful product. As stated by Ohgren et al. (2007). 70% of corn residue can be collected from a corn field without causing any soil problems, such as erosion or lack of nutrient replenishment. On a large scale, farmers in Arkansas have very little practical use for the crop residue in their fields

Methods

The end goal of this set of methods is to be able to rank selected counties in northeastern Arkansas by their output of cellulosic biomass by a thirteen year average. There were two main sections in the research process: the data collection and data analysis. The data collection was mainly done in ArcGIS and the data analysis was done in Microsoft Excel.

Data Collection

The software program ArcGIS is capable of analyzing and synthesizing spatial data into a useful format. Specifically for this project the ArcGIS program was used to quantify land usage on a per county basis. The two pieces of data used for this quantification were the Cropland Data Layer (CDL) and a shapefile of Arkansas counties.

The CDL is a survey of the land usage for the entire United States. It is a “census by satellite” for land usage (Beard 2013). The CDL is raster data (Appendix 1), usually with a pixel size of 30m by 30m. There were 255 different pixel value possibilities, this included corn (row id #2) to blueberries (row id #243).

The Arkansas County data was vector data (Appendix 1) that included all 75 Arkansas county boundaries and each county’s name was attached to the boundary.

The Spatial Analyst toolbox was used to find out how much of each pixel type was located within each county. Specifically the Zonal Histogram tool was used to accomplish this goal. This tool created a table with the zones (counties) as columns and

the pixel types as the rows. The outputted table had all 75 counties as the column headings and then listed how much of each pixel value was located in that specific county. For example there were 18,642 rice pixels in Faulkner County for the year 2000.

This method was used for the CDL data from 1999 – 2011. For each year of CDL data a unique table was created using the Zonal Histogram tool.

Data Analysis

The tables were still in the ArcGIS program at this point. The tables were exported from ArcGIS format to a “.txt” format. The files were then opened in Excel and the ‘Text to Columns’ tool was used to get the data back into table format in Excel. Next the data was ‘cleaned up’ and made easier to analyze. First some pixel values were just blank; they had a ‘Row ID #’ but did not have a descriptive name such as ‘corn’. The pixel values without a descriptive name did not have any pixels counted by the zonal histogram tool. Next the pixel values that did have a descriptive name but no pixels for that value were counted in the table needed to be deleted. Two extra columns were created next to the data to determine if a crop type had any data. One column summed up all the pixels for a given crop type. The second column used the ‘IF’ function to determine if there were any counted pixels for that given pixel value. The next step was to eliminate the columns for the counties that were not being analyzed in this study. The selected counties were Poinsett, Phillips, Crittenden, Cross, Clay, Greene, Mississippi, Lee, St. Francis, and Craighead. In all 65 columns were eliminated from the table to isolate the ten selected counties in northeastern Arkansas.

After the ‘clean up’ of the data the actual analysis was ready to be done. The pixel values that would be counted were: corn, rice, soybeans, and sorghum. However, in the table there were some pixel values named “Dbl Win Wheat/ Soybeans”. There was no way to tell what percentage of this pixel value represented Winter Wheat or Soybeans. There were several other pixel values that combined different land usage types. For this study these values were not used in any of the calculations for dry tons of biomass (corn, rice, soybeans, or sorghum) per county.

Once these pixel value rows were eliminated from the table, the value of dry tons of biomass was ready to be calculated. (From now on the ‘cleaned up’ table that was imported from ArcGIS will be referred to as Pixel Value [PV] table and the table created from the equation will be referred to as Equation Table) This was done by creating the equation table underneath the existing PV table. The equation table took the value from the PV table and calculated the tons of dry biomass in one calculation. The click and drag function was used to do this calculation for all valid pixel value rows and for all ten counties.

Below are the equations used to calculate the four different crop grains and residues for the year 2000. Each year had unique conversion factors in quantity/area.

$$\text{Available Corn Stover (tons)} = \# \text{ of pixels} * \frac{900 \text{ m}^2}{1 \text{ pixel}} * \frac{0.000247105 \text{ acres}}{\text{m}^2} * \frac{147.2 \text{ bushels}}{\text{acre}} * \frac{0.032 \text{ tons}}{\text{bushel}} \quad (1)$$

$$\text{Rice Harvested (tons)} = \# \text{ of pixels} * \frac{900 \text{ m}^2}{\text{pixel}} * \frac{0.000247105 \text{ acres}}{\text{m}^2} * \frac{7087 \text{ lb}}{\text{acre}} * \frac{1 \text{ ton}}{2000 \text{ lb}} \quad (2)$$

$$\text{Soybeans Harvested (bushels)} = \# \text{ of pixels} * \frac{900 \text{ m}^2}{\text{pixel}} * \frac{0.000247105 \text{ acres}}{\text{m}^2} * \frac{41.9 \text{ bushels}}{\text{acre}} \quad (3)$$

$$\text{Sorghum Harvested (bushels)} = \# \text{ of pixels} * \frac{900 \text{ m}^2}{\text{pixel}} * \frac{0.000247105 \text{ acres}}{\text{m}^2} * \frac{54.6 \text{ bushels}}{\text{acre}} \quad (4)$$

The four equations above were used to calculate the corn stover, rice, soybean, and sorghum values for each individual county for the years 1999 – 2011. The pixels were 30m by 30m therefore giving the pixel an area of 900 m^2 . The yields were given in bushels per acre so square meters were converted to acres. The grain yield values for each year of corn, rice, soybeans, and sorghum grain were obtained from National Agricultural Statistics Service's website (<http://www.nass.usda.gov/>). The value for corn stover per bushel was taken from a report by Michigan State University on harvesting corn residue yields (Gould 2009).

Results

After analysis, the ten selected counties were ranked by how much of each crop type was produced. The production values, yearly totals from 1999-2011, were used to rank the counties. Corn stover production was accounted for in dry tons of residue available. Unfortunately, corn was the only commodity for which the actual amount of residue was quantified; this was possible because a value for available residue was obtained in the literature (Gould 2009). Because no values for rice, sorghum, and soybeans residues were located in the literature, the analysis results are reported in terms of crop productions. Table 1 presents, the yearly the crop production values for corn, rice, sorghum, and soybeans, and are listed for the ten selected counties. For a better spatial representation of corn stover data see figure 3. Rice was calculated and presented as dry tons of rice grain harvested. The value for rice residue was not calculated due to lack of reliable sources. For a better spatial representation of the data see figure 4. Sorghum and soybean production was calculated as bushels harvested. There was no reliable conversion factor to convert bushels harvested to mass harvested. For a better spatial representation of the sorghum data see figure 5 and figure 6 for the soybean data.

Table 1. Crop Production Averages (1999-2011)

County Name	<i>Corn</i>^[a]	<i>Rice</i>^[a]	<i>Soybeans</i>^[b]	<i>Sorghum</i>^[b]
Clay	75,489.73	195,959.44	3,701,705.89	71,440.09
Craighead	43,718.80	201,468.49	3,504,413.27	127,854.14
Crittenden	30,863.48	100,812.43	5,594,188.92	410,483.71
Cross	20,112.13	245,180.90	4,733,615.23	197,174.55
Greene	38,277.67	185,863.53	2,833,743.08	89,324.05
Mississippi	52,738.39	108,772.98	5,927,001.94	233,189.95
Poinsett	26,881.32	305,897.06	5,131,716.10	123,019.84
St. Francis	36,028.20	142,012.12	4,714,419.53	308,642.26
Lee	52,978.04	85,941.47	4,384,363.37	303,171.24
Phillips	61,691.54	75,814.23	5,555,053.47	307,288.87

[a] Units measured in dry tons

[b] Units measured in bushels

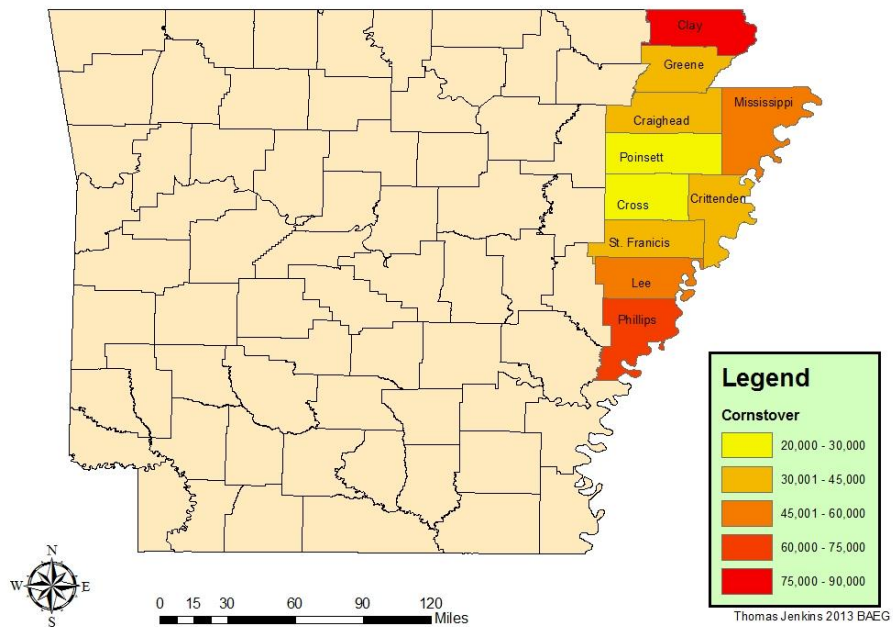


Figure 3. The ten selected counties are displayed above with a gradient scale where red denotes the most corn stover production and yellow represents the least corn stover production.

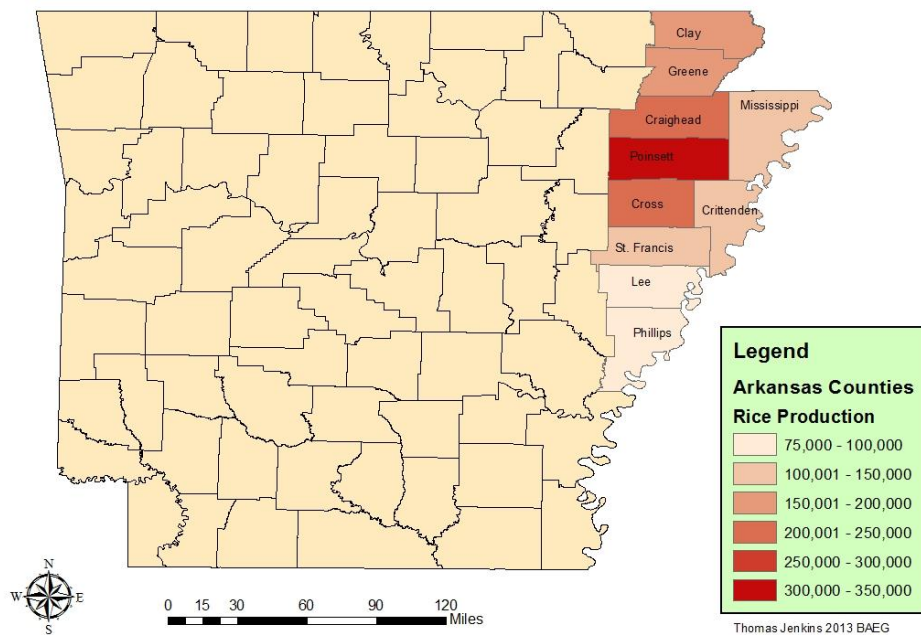


Figure 4. The ten selected counties are displayed on a gradient scale where red denotes the most rice production and white represents the least rice production.

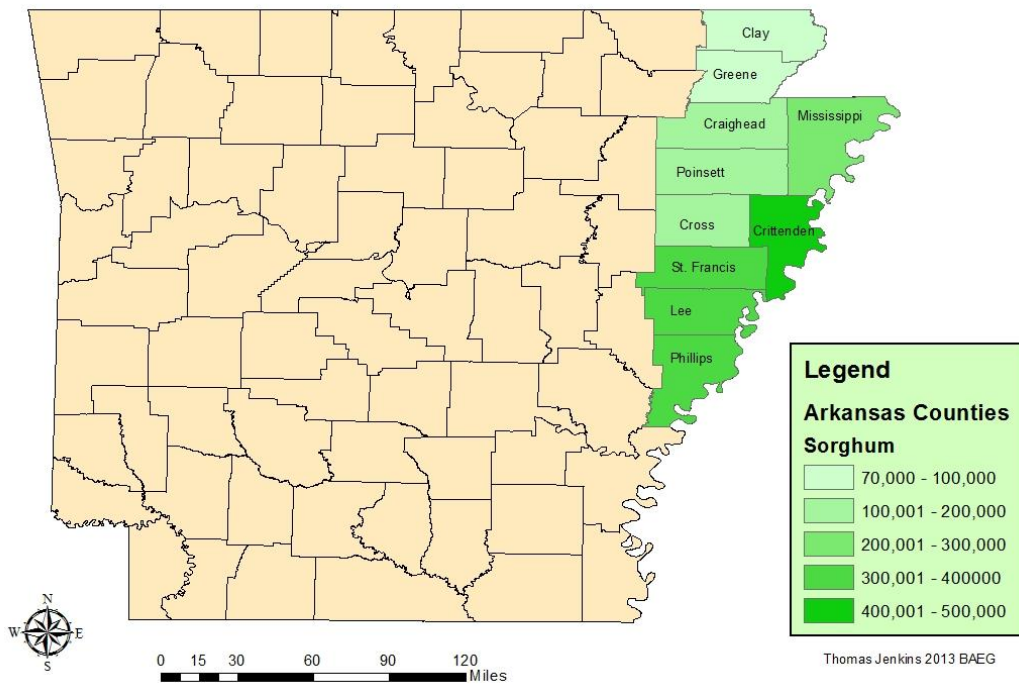


Figure 5. The ten selected counties are displayed on a gradient scale where dark green denotes more sorghum harvested and light green denotes less sorghum harvested.

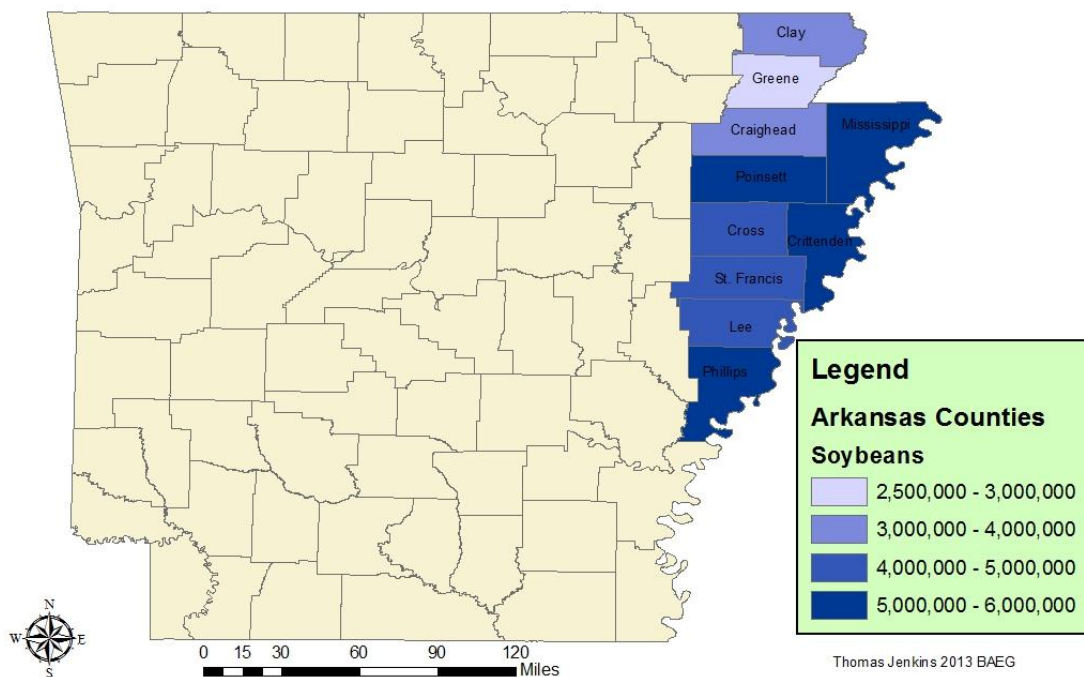


Figure 6. The ten selected counties are displayed on a gradient scale where dark blue denotes more soybeans produced.

Discussion

Sources of Error

The calculated crop residue and grain totals are higher than the true crop production. Due to the use of raster GIS data (Appendix 1) CDL data that was used in the calculation had a grid that had 900 m^2 squares. If the computer determines a pixel value by what takes up the majority of the 900 m^2 then roads, houses, and other buildings may be counted as agriculture. The best way to get a more accurate measure of what the 'true' crop production is to decrease the pixel size. Decreasing the pixel size would give more accuracy to the CDL and results.

For any agricultural product, there must be a certain amount of crop residue left in the field to replenish the soil's nutrient supply. The corn stover values calculated did not take this into account. One source claimed that 70% of crop residue could be taken from the fields Ohgren et al. (2007) However, this study was conducted in Sweden; therefore this percentage may change, depending on the specific location of the crop and location field being analyzed.

Interpretation of Data

The top three corn producing counties in Arkansas were: Clay, Phillips, and Lee counties. Clay County is the northern most county in the state and Phillips and Lee counties are the two southernmost counties in the state. The top three rice producing counties of those considered in Arkansas were: Poinsett, Cross, and Craighead

counties. These three counties are all located right next to each other in the middle of the ten selected counties. The top three sorghum producing counties in Arkansas were: Crittenden, St. Francis, and Lee counties. The top three soybean producing counties in Arkansas were: Mississippi, Crittenden, and Phillips. Mississippi and Crittenden counties share a border in the middle of the state but Phillips County is in the southern part of the state and does not border either county. However, only one county of the ten selected counties produced less than three million bushels of soybeans. The rest of the ten selected counties produced at least three million bushels of soybeans.

The total amount of available biomass was unable to be accurately calculated in this study due to lack of data to convert grain yields of rice, sorghum, and soybeans into cellulosic biomass values. If future data is taken of rice, sorghum, and soybean residue yields then the amount for available cellulosic biomass in northeastern Arkansas will be possible to calculate.

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Appendix 1 - Raster Data explained

The program ArcGIS recognizes two types of data: raster and vector.

Vector data is easy to remember because it is just points, lines, and polygons. An example of each of these on a map would be a flag pole, a road, and lake.

Raster data is slightly different; it is composed of a grid. Each square in the grid is called a pixel; see Figure 1 for a visual aid.

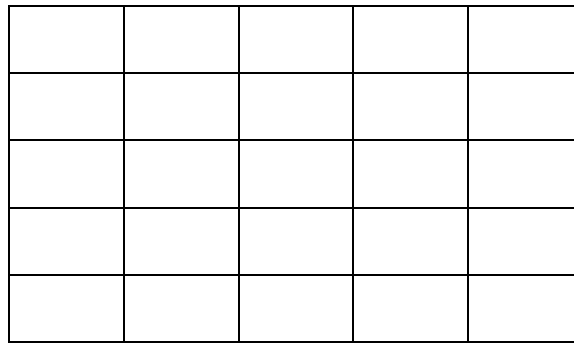


Figure 1. Example of a raster image, each square is the same length and width.

Raster data differentiates from vector data because the grid represents data based on the majority of what is in the pixel. If an area containing a lake, road, and field was in vector format it would look similar to figure 2. Converting the area to raster requires overlaying the grid similar to the one in figure 1. Inevitably some squares will not overlay perfectly with the terrain. For example the lake boundary may go through the middle of a square on the grid. This is where the computer must make a decision on what value to assign to the cell. Typically a pixel cell is defined by what occupies the majority of its area. So in the lake example if the lake takes up more than 50% of the cell's area then it will be classified as a lake cell and not a land cell.

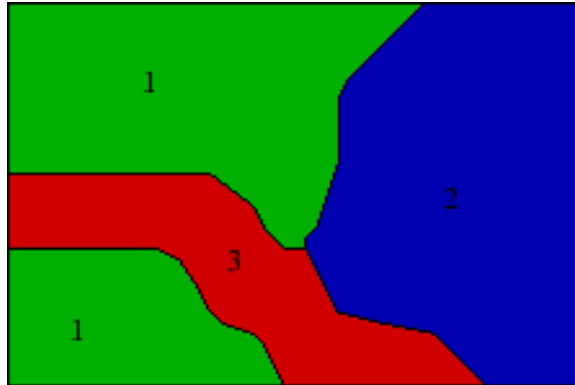


Figure 2. The green areas represent land (1), the blue area represents the lake (2), and the red area represents the road (3). (Institute of Cartography 2010)

Figure 4 is what the final raster data layer would look like. Raster data is not as accurate as vector data when it comes to the exact area of a particular polygon. However, this error can be minimized for by making the pixel size of the grid as small as possible. The smaller the pixel grid is, the more accurate the data will be.

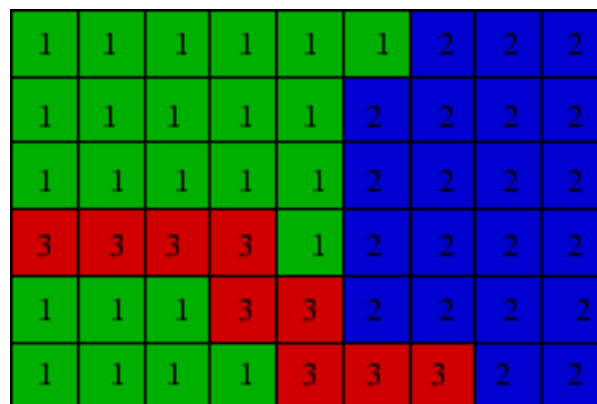


Figure 3. The same piece of area as figure 3, but the area is now in a raster format. (Institute of Cartography 2010)